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Bethesda, Maryland 20084

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COMPARATIVE SEAKEEPING CHARACTERISTICS OF TWO UNITED STATES COAST GUARD PATROL BOATS IN REGULAR WAVES

by

N. K. Bales

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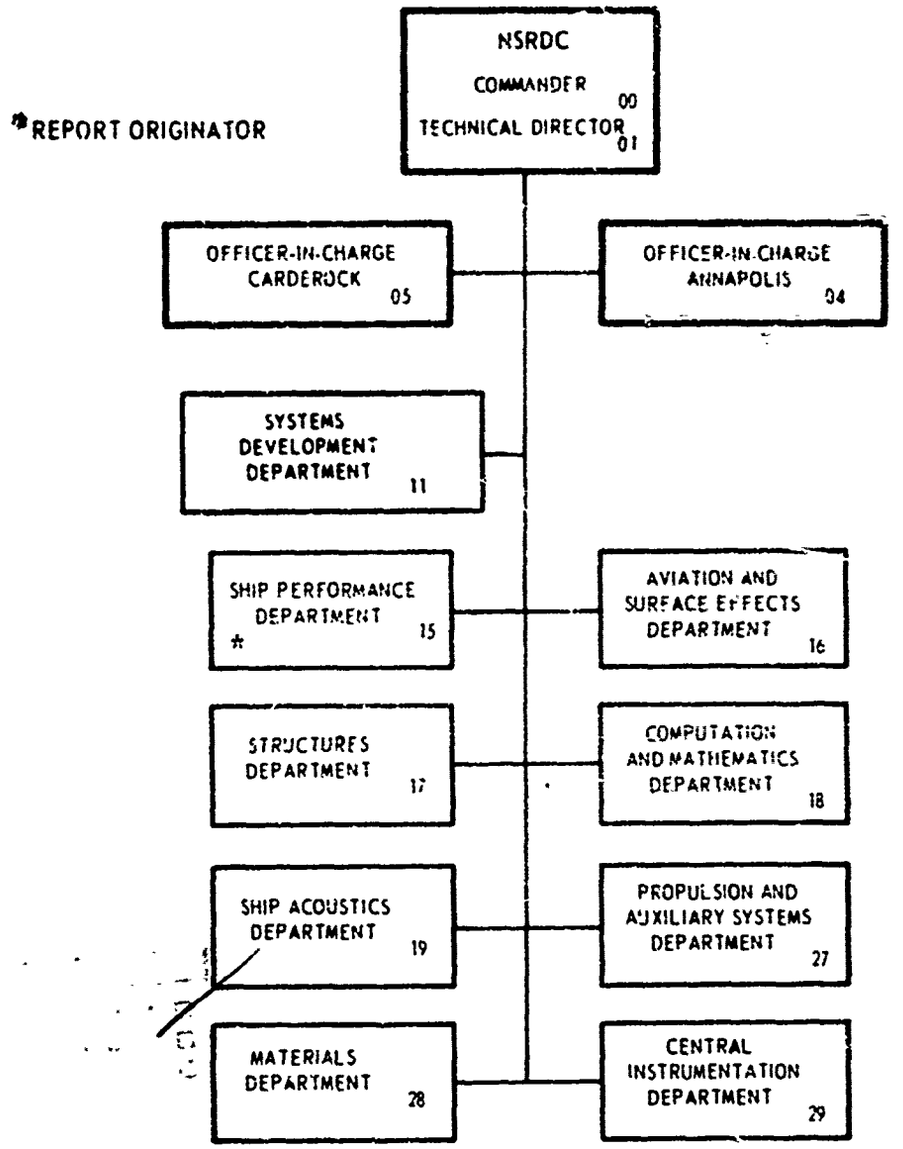

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The seakeeping characteristics of two, United States Coast Guard patrol boats (a 95-foot WPB and a 140-foot WAGB) are compared. The comparison is based on computed, nondimensional, responses in regular waves. On this basis, the seakeeping characteristics of the 95-foot boat are found to be superior to those of the 140-foot boat.

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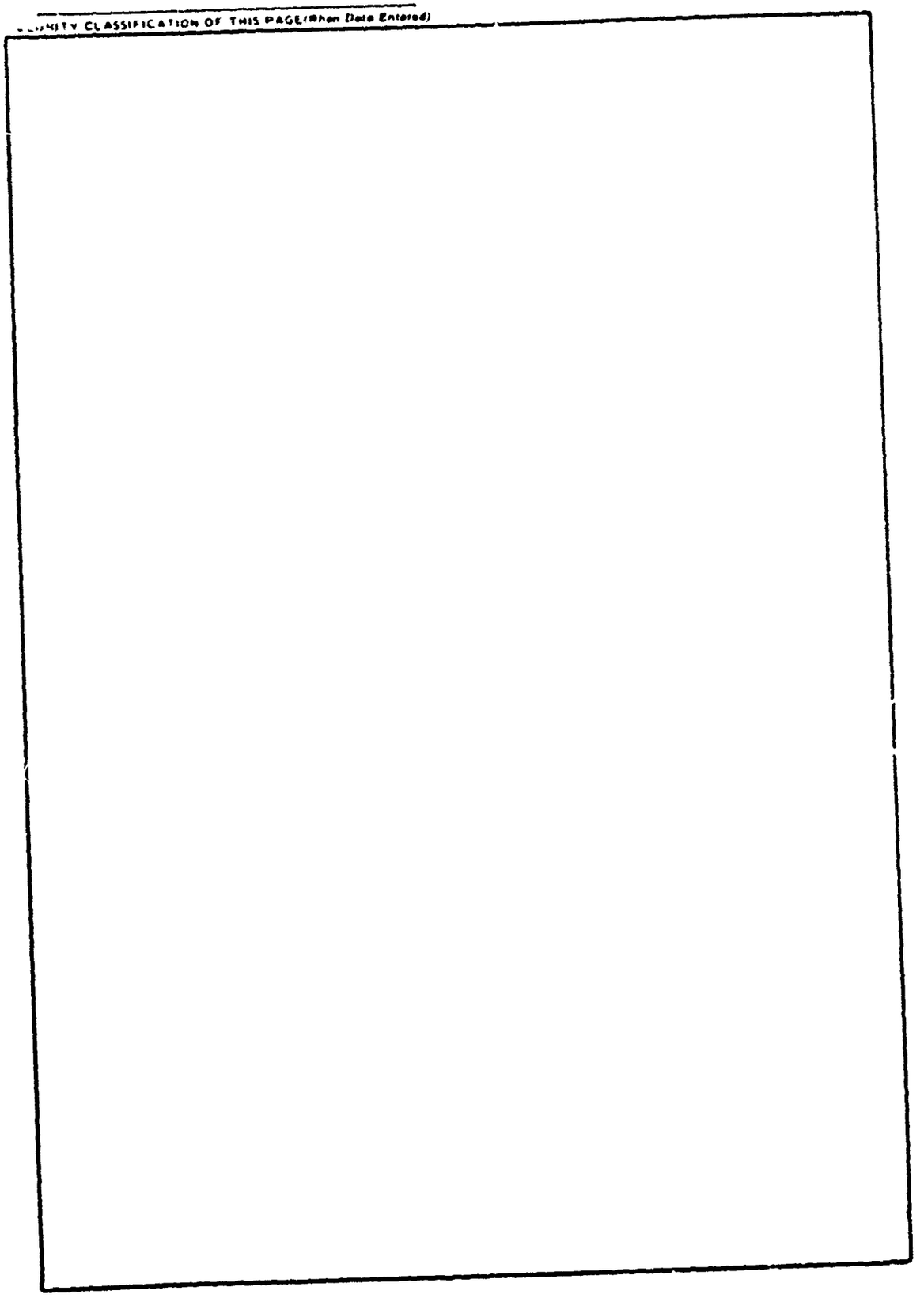

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NOTATION

B_x	Maximum beam on load waterline
F_n	Froude number
L_{BP}	Ship length between perpendiculars
T_M	Draft amidships
$\overline{GM}$	Metacentric height
$\overline{KB}$	Vertical distance from center of buoyancy to keel
LCB	Longitudinal center of buoyancy
LCF	Longitudinal center of flotation
$\overline{ZG}$	Vertical distance from load waterline to center of gravity
g	Acceleration of gravity
k_θ	Radius of gyration in pitch
k_ϕ	Radius of gyration in roll
$\ddot{s}_A$	Single amplitude of absolute vertical acceleration
z_A	Single amplitude of heave
Δ	Ship displacement
μ	Heading of ship relative to waves
$\epsilon_{z\theta}$	Heave-to-pitch phase angle
ζ_A	Single amplitude of wave
θ_A	Single amplitude of pitch
ν_M	Maximum wave slope
ϕ_A	Single amplitude of roll
λ/L	Ratio of wavelength to ship's length between perpendiculars

ABSTRACT

The seakeeping characteristics of two, United States Coast Guard patrol boats (a 95-foot WPB and a 140-foot WAGB) are compared. The comparison is based on computed, nondimensional, responses in regular waves. On this basis, the seakeeping characteristics of the 95-foot boat are found to be superior to those of the 140-foot boat.

ADMINISTRATIVE INFORMATION

The work reported herein was funded by the United States Coast Guard under Military Interdepartmental Purchase Request Z-70095-4-44131, and was identified at the David W. Taylor Naval Ship Research and Development Center as Work Unit Number 1-1568-013.

INTRODUCTION

The United States Coast Guard (USCG) requested that the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) prepare a proposal to compare the seakeeping characteristics of two USCG patrol boats.

The two boats differ considerably in both gross size and hull form. Further, their operational area overlap is ill-defined. Hence, DTNSRDC proposed that the comparison be made on a nondimensional basis using computed, regular wave responses. The USCG accepted this proposal, and work was initiated at DTNSRDC. This report documents the results of the DTNSRDC effort.

DATA BASE COMPUTATIONS

Responses to be compared were roll amplitude over maximum wave slope (ϕ_A/ν_M), pitch amplitude over maximum wave slope (θ_A/ν_M), heave amplitude over wave amplitude (z_A/ζ_A), and absolute vertical acceleration in gravity units ($\ddot{s}_A/g$). For each boat, these responses were to be computed for all combinations of three Froude numbers (F_n), 'round the clock relative headings (μ) at

30-degree increments, and at least 10 wavelength to ship length ratios (λ/L). The DTNSRDC Ship Motion and Sea Load Computer Program, reference 1*, was to be used for the motion computations. Subsequently, acceleration was to be computed using the data obtained from the cited program.

Offsets were read from the lines of the two boats to provide input for the Ship Motion and Sea Load computer program. The resultant hull models are delineated by Figures 1 and 2 and by Table 1. It should be noted that the gross hull dimensions and inertial characteristics presented in Table 1 were input directly, but that the hydrostatic properties given in the same table were computed using the offset data.

The maximum speed of the 95-foot boat corresponds to $F_n = 0.63$ while that of the 140-foot boat corresponds to $F_n = 0.44$. Hence, in view of the comparative nature of the investigation, it was decided to adopt $F_n = 0.44$ as the maximum value for data base computations. The remaining two Froude numbers were arbitrarily specified to be 0.10 and 0.27.

Specification of λ/L values from 0.2 to 2.0 in increments of 0.1 and thence to 3.6 in increments of 0.2 completed preparation of input for the Ship Motion and Sea Load computer program. Computations were subsequently performed for both boats. Preliminary inspection of the results of these computations indicated two problem areas. The iterative procedure used by the program to determine rolling motion did not converge properly for the 140-foot boat, and very large pitch and heave amplitudes were predicted for both boats in following and near-following waves at the higher Froude numbers.

The rolling motion of the 140-foot boat was recomputed using the technique described in reference 2. No comparable alternative existed for computing pitch and heave, so the amplitudes were accepted as originally computed. It is of interest to note that experiments with radio-controlled models, reference 3, have indicated that broaching-to may occur under conditions similar to those for which the seemingly excessive pitch and heave amplitudes were predicted.

Absolute vertical acceleration at an assigned location includes a pitch-induced component proportional to the distance from the center of pitch (assumed

*References are listed on page 6.

to be the LCB) to the assigned location. It was felt that this distance should be made equal for the two boats in order to compare them on a fair basis. Hence, the distance was taken to be that from the LCB to the forward perpendicular of the smaller boat, i.e., 49.7 feet.

Acceleration amplitudes at the specified location were computed as the second time derivative of the vector sum of heave and pitch components. For these computations it was assumed that θ_A in radians was equal to the tangent of θ_A, i.e., that θ_A was "small." The actual discrepancies between θ_A in radians and the tangent of θ_A were always less than three percent.

ANALYSIS

For each boat, the computations just described produced over 500 values of each response considered. So, an initial analysis procedure which would isolate critical areas for detailed investigation was needed. To this end, plots comparing the ranges of each response over λ/L at constant speed were constructed as a function of heading. The range minima proved to be of little interest: they were nearly identical for the two boats, and were typically on the order of zero. Range maxima, on the other hand, gave the desired indication of critical areas. So, maxima plots are presented by Figures 3 through 14.

The maxima plotted in each of these figures apply to a λ/L range from 0.2 to 3.6. Heading is defined such that $\mu = 180$ degrees implies head waves, and straight lines are arbitrarily used to connect points at the headings for which computations were made. Response scales are kept constant across speed, and the larger pitch and heave maxima which occurred in following and near-following waves are off-scale. However, the missing points are indicated by arrows; and their numerical values are supplied.

Roll maxima for the two boats, see Figures 3, 4 and 5, differ significantly in magnitude and/or trend at all Froude numbers.

Across heading, the 140-foot boat always exhibits higher maxima than the 95-foot boat. The greatest difference occurs at $\mu = 90$ degrees and $F_n = 0.10$ (Figure 3) where the roll of the 140-foot boat is more than twice that of the 95-foot boat. Transfer functions for the two boats in the maximum difference

condition are compared in Figure 15. The large difference is not surprising in view of the sectional shapes of the two boats.

With respect to trend differences in roll, it is apparent from Figures 3 through 5 that the 140-foot boat rolls more in beam and quartering regular waves while the 95-foot boat rolls more in bow regular waves. This situation is attributable to the difference between the rolling periods of the two boats. As can be inferred from Figure 15, the 140-foot boat has a much longer roll period than the 95-foot boat. So, bow regular wave encounter frequencies tend to excite the 95-foot boat at roll resonance; but do not attain the relatively low values associated with roll resonance for the 140-foot boat. Figure 16 illustrates this point.

Regions of ill-defined pitch maxima (see Figures 6 through 8) occur at $\mu = 0$ degrees and $\mu = 30$ degrees when $F_n = 0.27$ and $F_n = 0.44$. Elsewhere, the pitch maxima for the two boats exhibit similar trends. Magnitudes are larger for the 140-foot boat, and the discrepancies increase with F_n. The largest discrepancies occur at $F_n = 0.44$ when $\mu = 150$ degrees and when $\mu = 180$ degrees. Then the pitch of the 140-foot boat reaches twice that of the 95-foot boat. Figure 17 compares pitch transfer functions for the $\mu = 180$ degree case.

The tenor of the heave maxima results presented in Figures 9, 10 and 11 is similar to that just described for pitch. However, the largest differences in heave never reach the factor-of-two level associated with roll and pitch. As detailed by Figure 18, the largest differences in heave are on the order of 60 percent.

The acceleration maxima for the two boats, as presented in Figures 12 through 14, exhibit similar trends and do not differ greatly in magnitude. Though the accelerations of the 95-foot boat are marginally higher than those of the 140-foot boat in most conditions, the major differences favor the 95-foot boat. Figure 19 shows acceleration transfer functions for the maximum difference case; here the acceleration of the 140-foot boat exceeds that of the 95-foot boat by about 30 percent.

Two additional notes are in order regarding the acceleration comparisons. First, the high values of pitch and heave which occurred in following and near-following regular waves at the higher Froude numbers were used to compute

accelerations for these conditions. However, the associated encounter frequencies were sufficiently low that the computed accelerations did not obviously reflect the large pitch and/or heave magnitudes. Second, the fact that the accelerations of the 95-foot boat sometimes exceeded those of the 140-foot boat in conditions for which the 140-foot boat experienced larger maximum pitch and heave was due to the more favorable phase relationships of the 140-foot boat. As computed, acceleration is proportional to the cosine of the heave-to-pitch phase angle, $\varepsilon_{z\theta}$. Figure 20 exhibits a plot of the cosine of $\varepsilon_{z\theta}$ for a condition such that the maximum accelerations of the 95-foot boat exceeded that of the 140-foot boat though the maximum pitch and heave of the 140-foot boat exceeded those of the 95-foot boat.

In summary, the most outstanding differences between the two boats occur in beam regular waves at $F_n = 0.10$ and in head regular waves at $F_n = 0.44$. In the former condition, the roll maximum of the 140-foot boat greatly exceeds that of the 95-foot boat. In the latter condition, the pitch, heave and acceleration maxima of the 140-foot boat significantly exceed those of the 95-foot boat.

CONCLUSION

The preceding analysis indicates that the seakeeping performance of the 95-foot boat is generally superior to that of the 140-foot boat. It should, however, be borne in mind that the analysis was based on nondimensional responses in regular waves. Comparing the dimensional responses of the two boats in identical, random waves could reverse the trend favoring the 95-foot boat if a family of narrow wave spectra with high modal frequencies was selected.

ACKNOWLEDGMENTS

Mr. T. Applebee of DTNSRDC was responsible for the computer applications required to generate the data base; and Mr. R. Watkins, also of DTNSRDC assisted with the data analysis effort.

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1. Meyers, W.G. et al., "Manual: NSRDC Ship Motions and Sea Load Computer Program," NSRDC Ship Performance Department Report 3376, February 1975.

2. Conolly, J.E., "Rolling and its Stabilization by Active Fins," Quarterly Trans. RINA, Vol. 111, No. 1, pp. 21-48, January 1969.

3. Nicholson, K., "Some Parametric Model Experiments to Investigate Broaching-to," Paper No. 17, International Symposium on the Dynamics of Marine Vehicles and Structures in Waves, University College, London, April 1974.

TABLE 1 - PROPERTIES OF THE 95-FOOT WPB AND OF THE 140-FOOT WAGB

Parameter	Units	95-foot WPB	140-foot WAGB
L_{BP}	feet	90.0	130.0
B_x	feet	18.4	33.7
T	feet	5.5	11.1
$\overline{ZG}$	feet	1.9	2.8
k_θ	feet	0.24 L_{BP}	1.24 L_{BP}
k_ϕ	feet	0.4 B_x	0.4 B_x
Δ	long tons in salt water	102	605
LCB	feet aft of midship	4.70	2.45
$\overline{KB}$	feet	3.64	6.78
LCF	feet aft of midship	7.90	1.59
$\overline{GM}$	feet	4.63	2.78

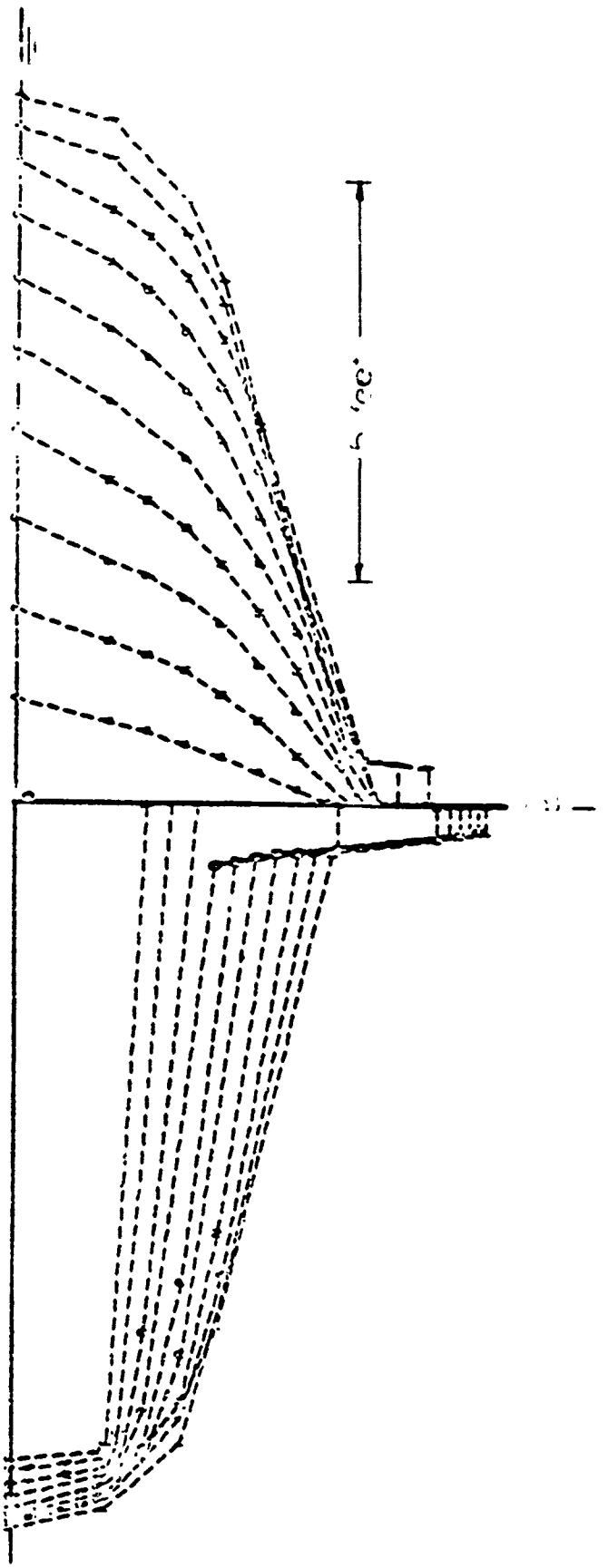

Figure 1 - Computer Representation of 95-foot WPB Hull

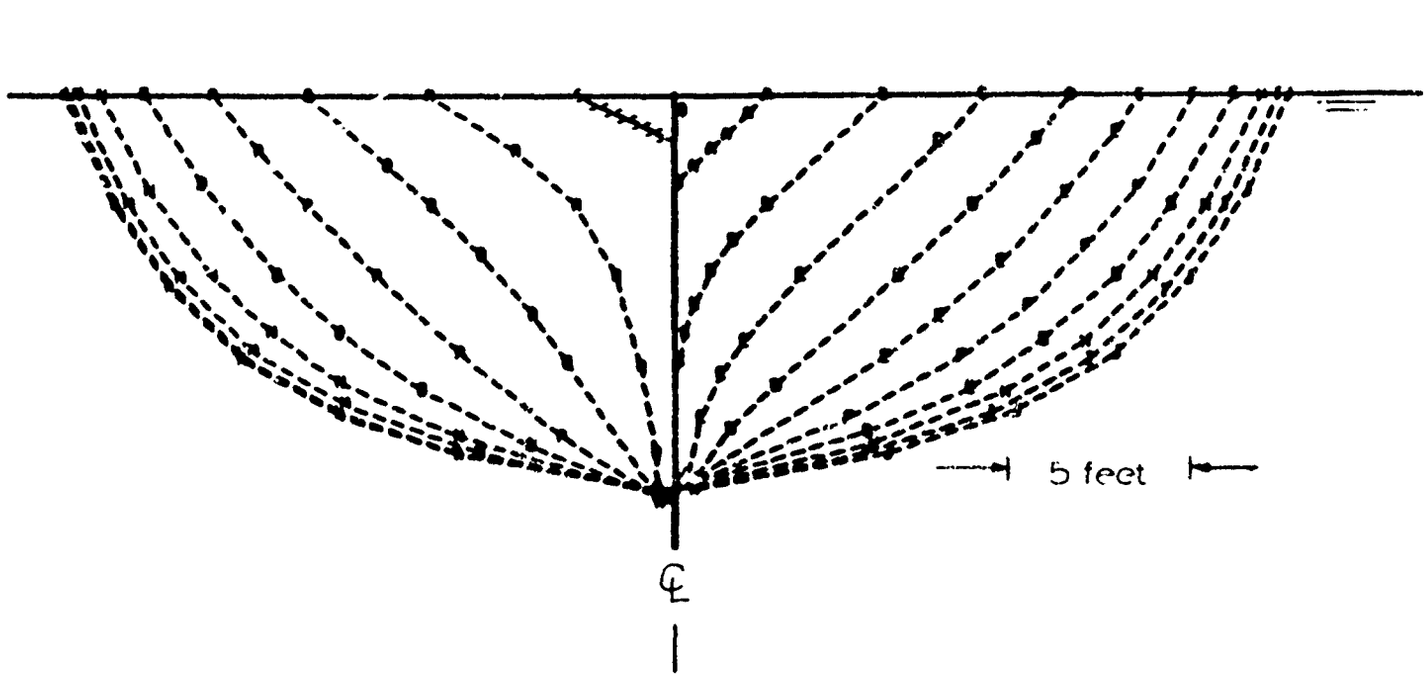

Figure 2 - Computer Respresentation of 140-foot WAGB Hull

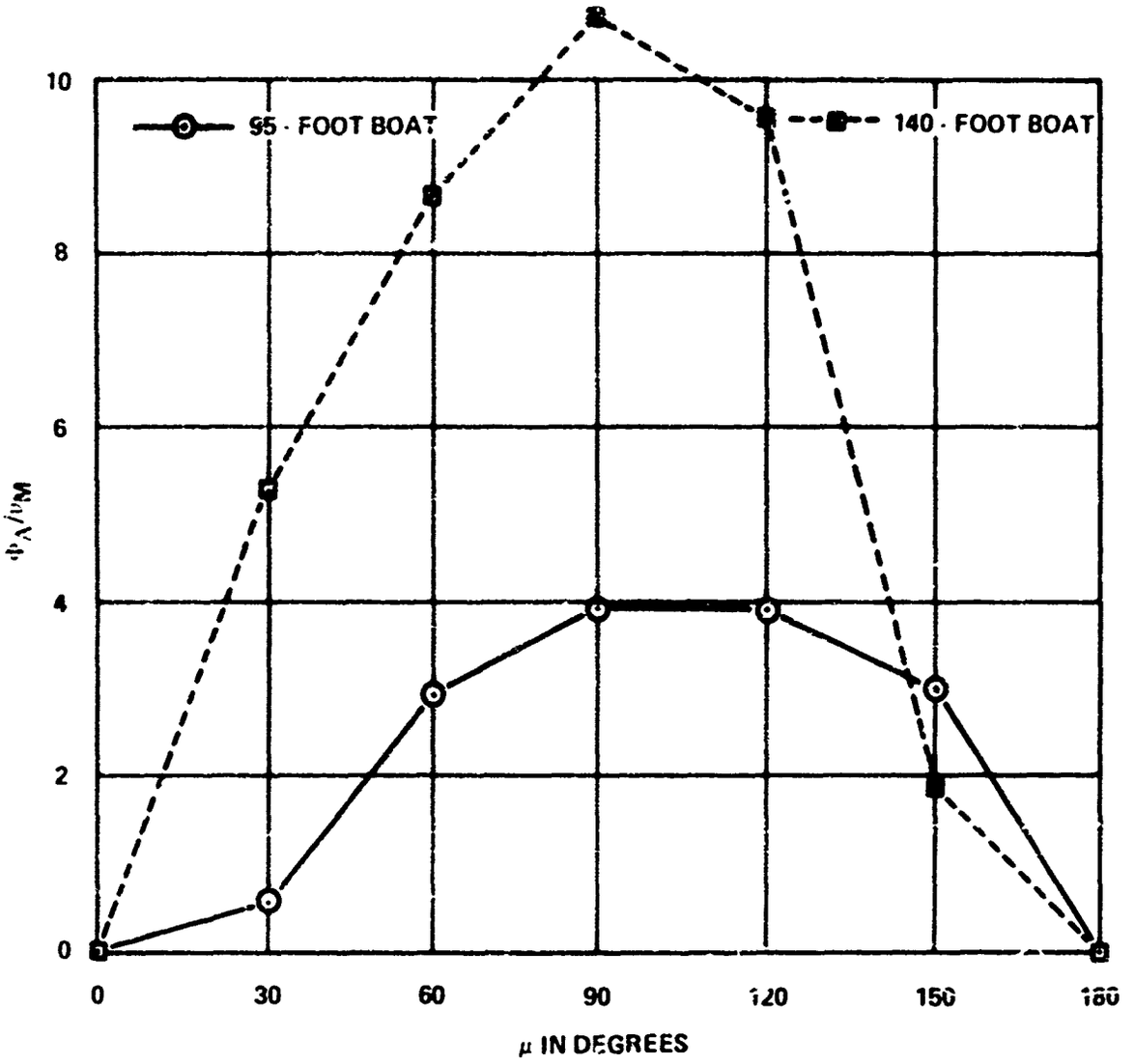

Figure 3 - Roll Maxima at $F_n = 0.10$

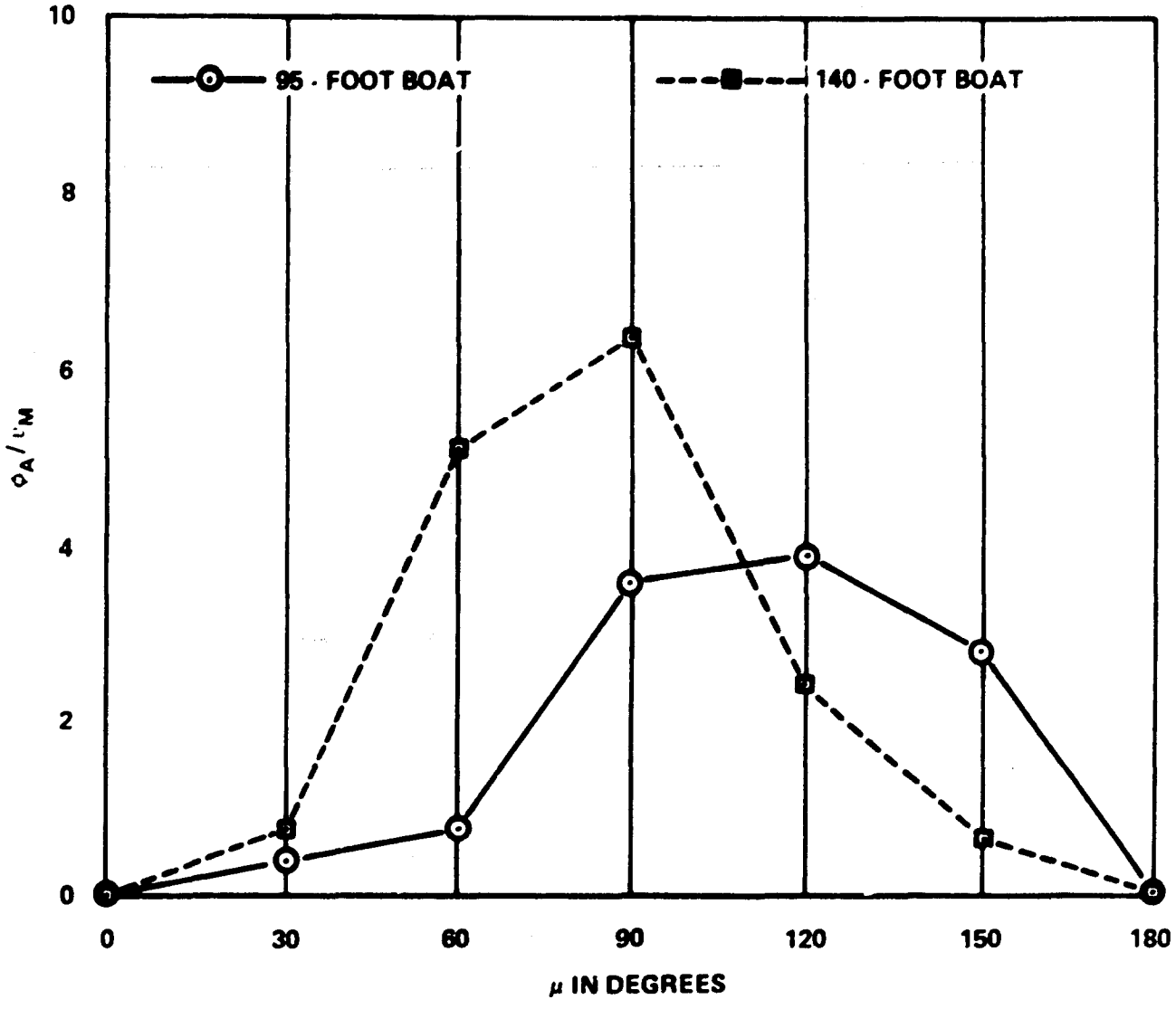

Figure 4 - Roll Maxima at $F_n = 0.27$

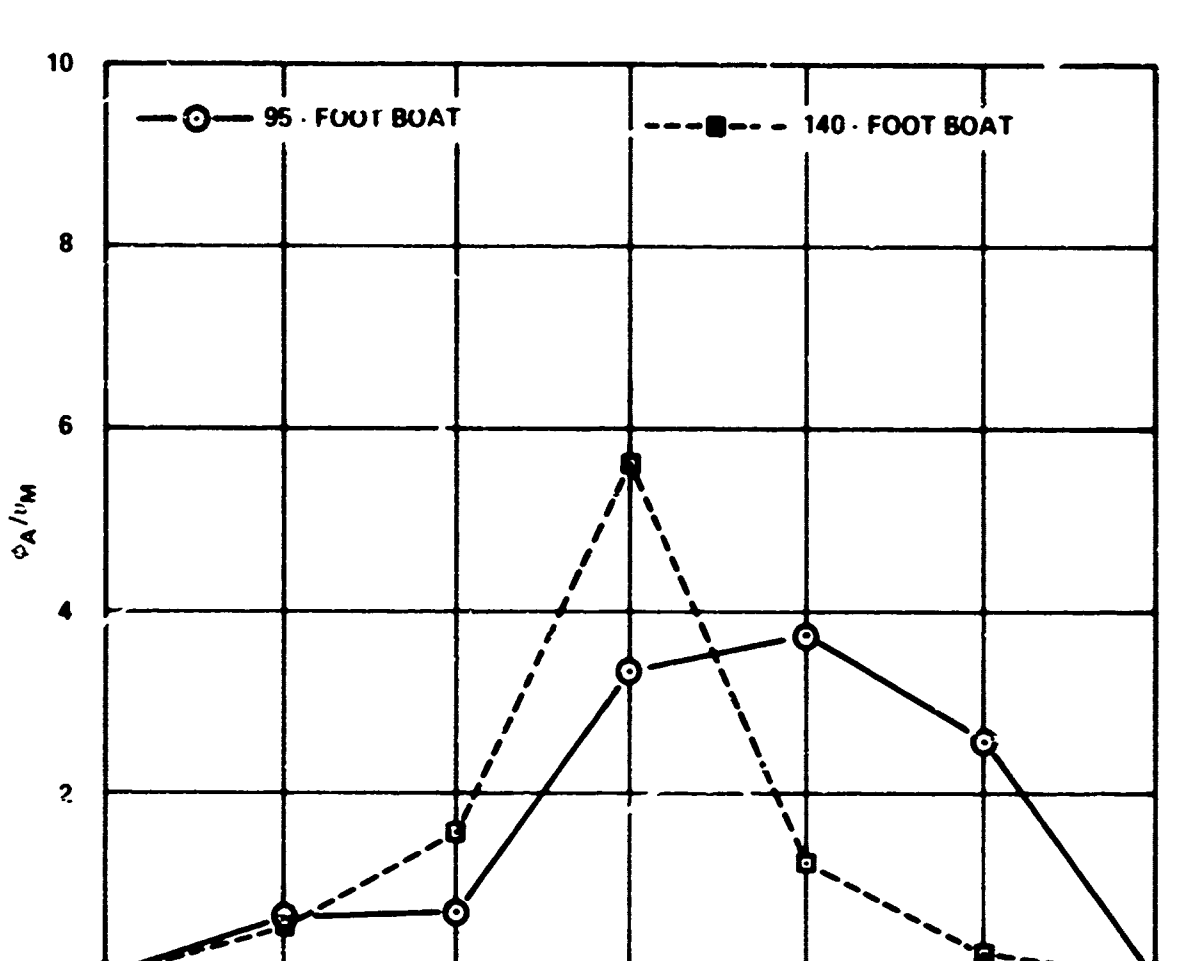

Figure 5 - Roll Maxima at $F_n = 0.44$

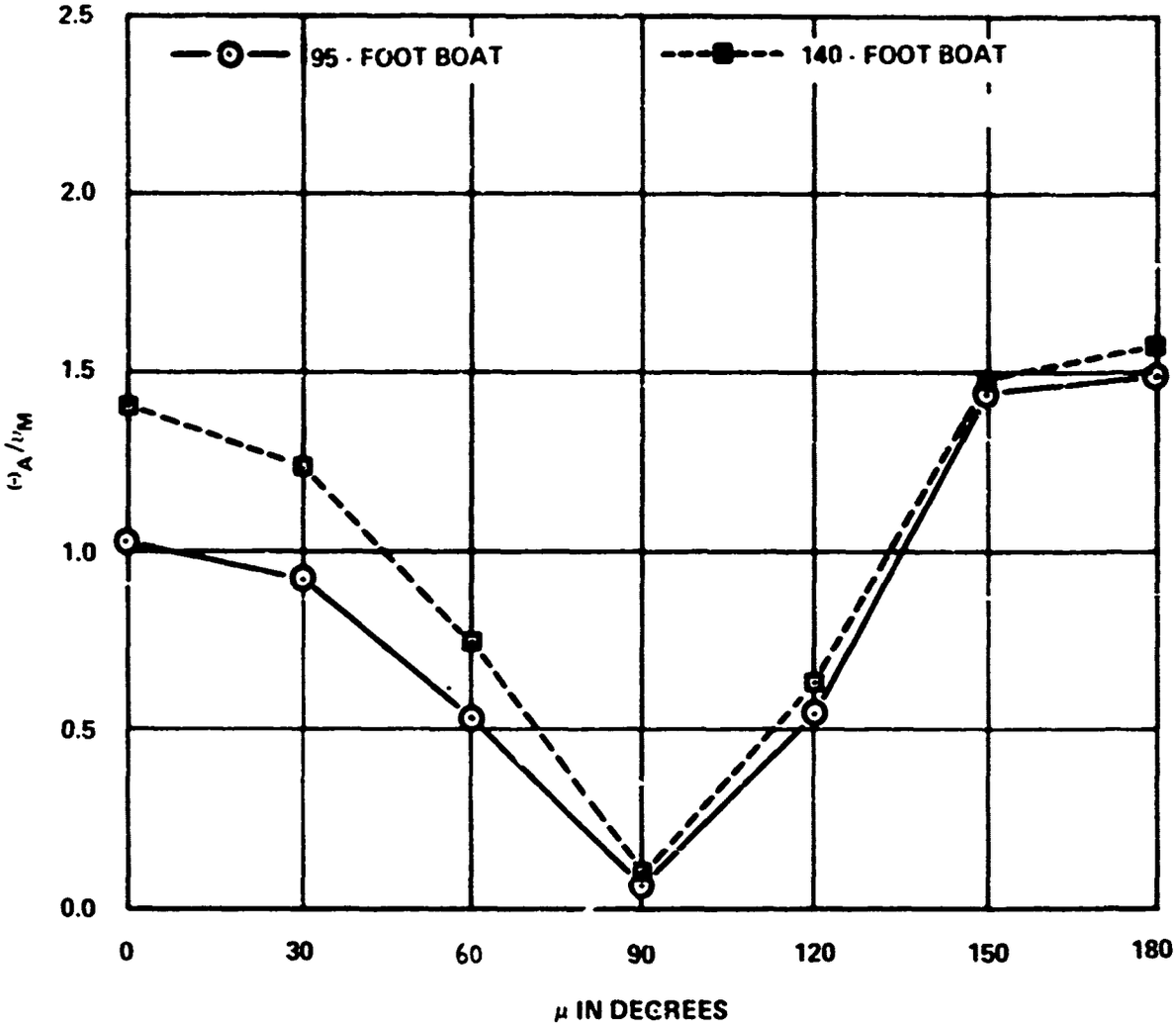

Figure 6 - Pitch Maxima at $F_n = 0.10$

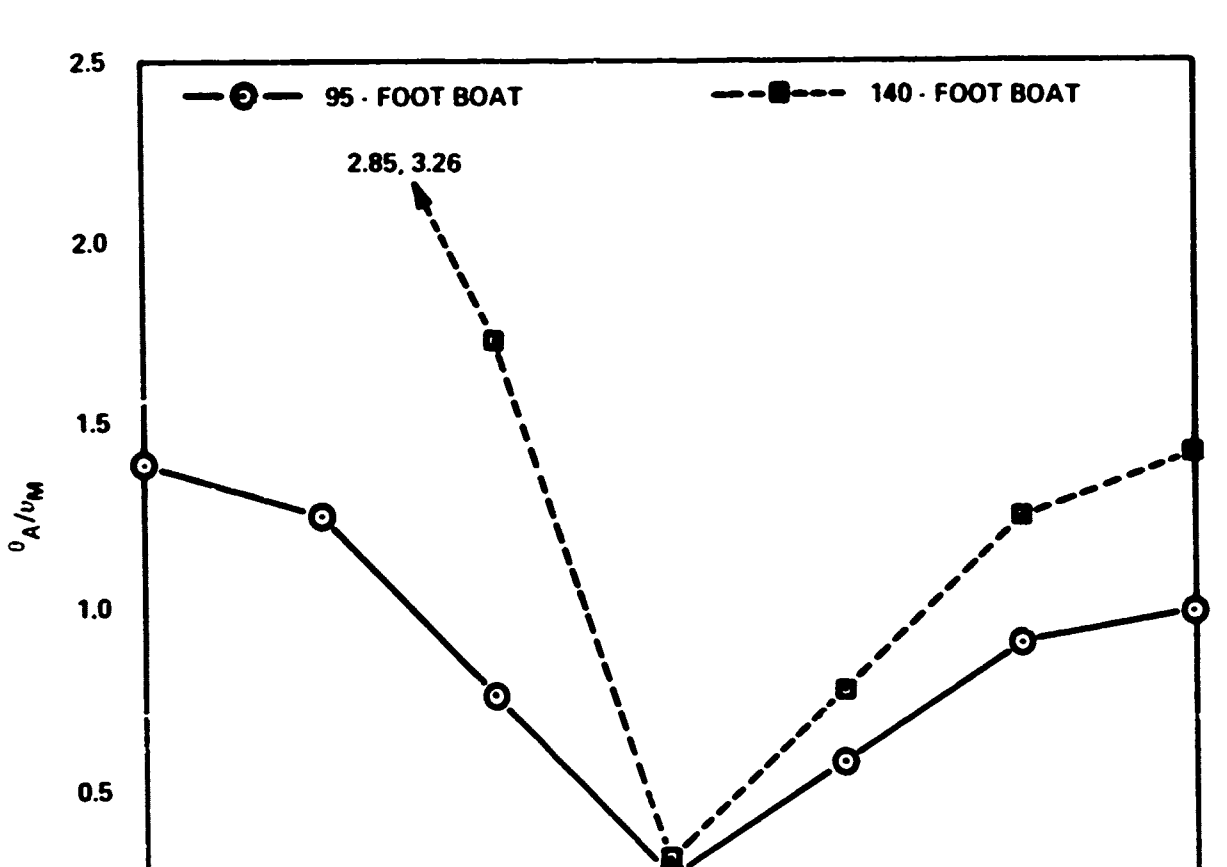

Figure 7 - Pitch Maxima at $F_n = 0.27$

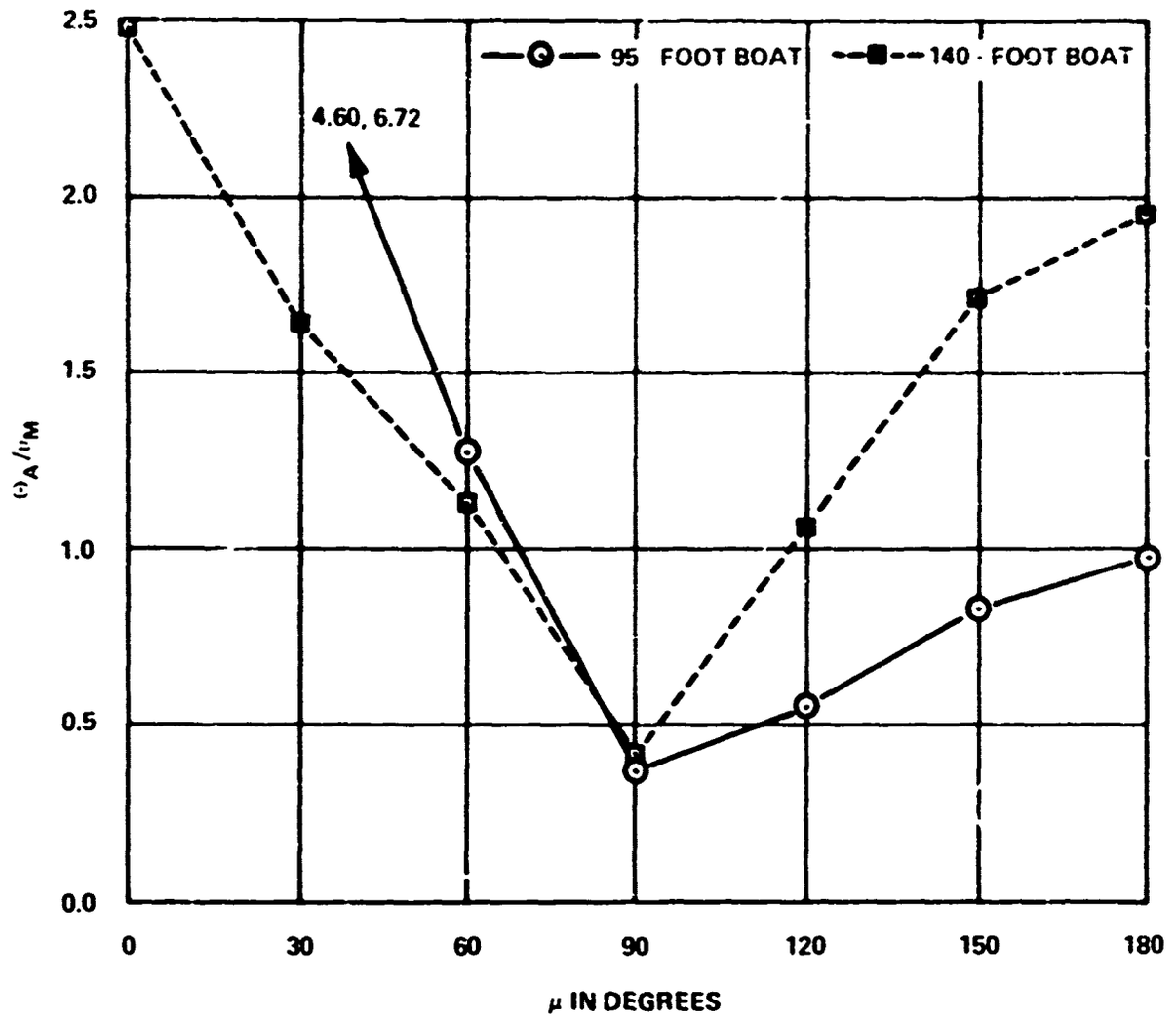

Figure 8 - Pitch Maxima at $F_n = 0.44$

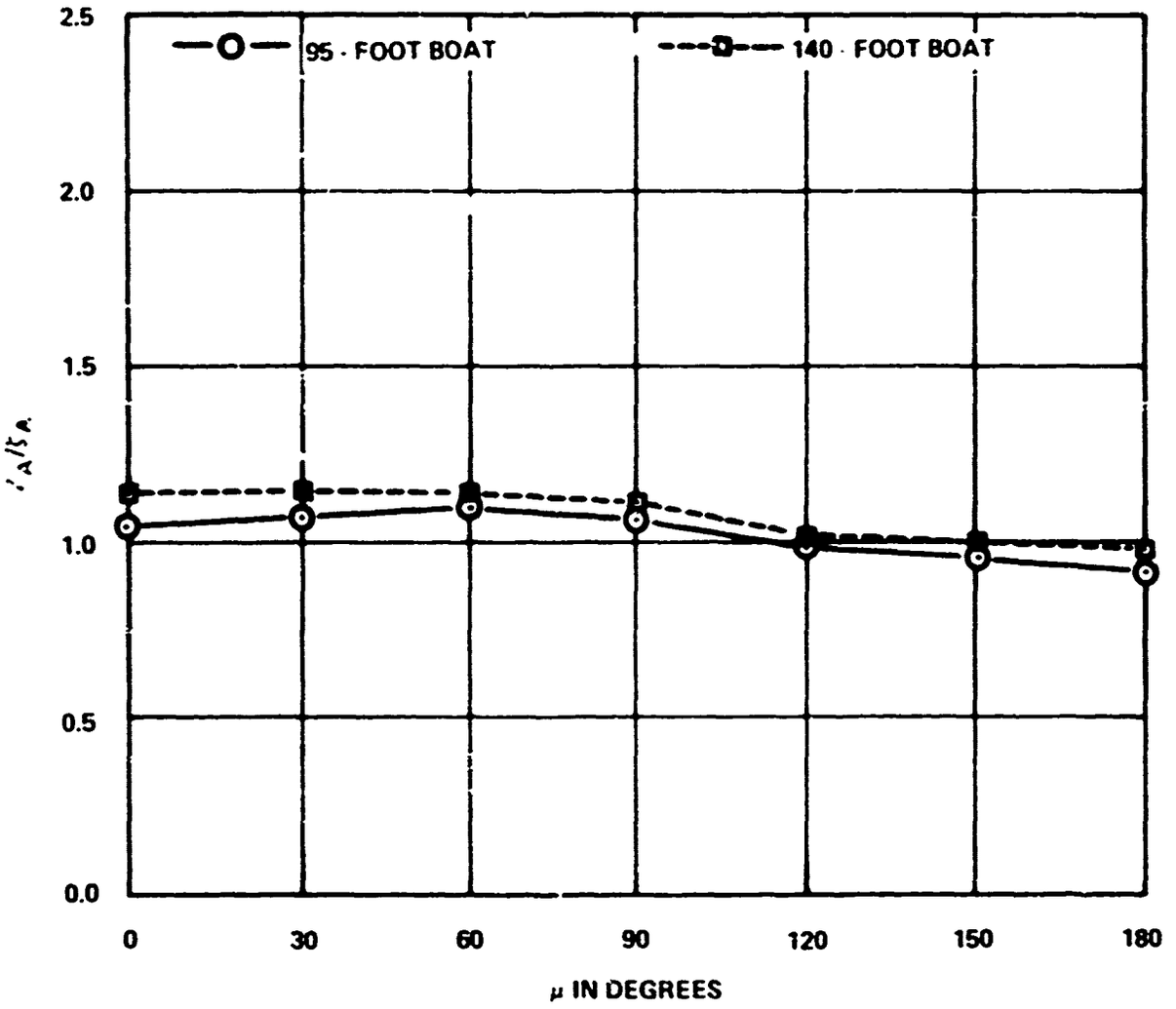

Figure 9 - Heave Maxima at $F_n = 0.10$

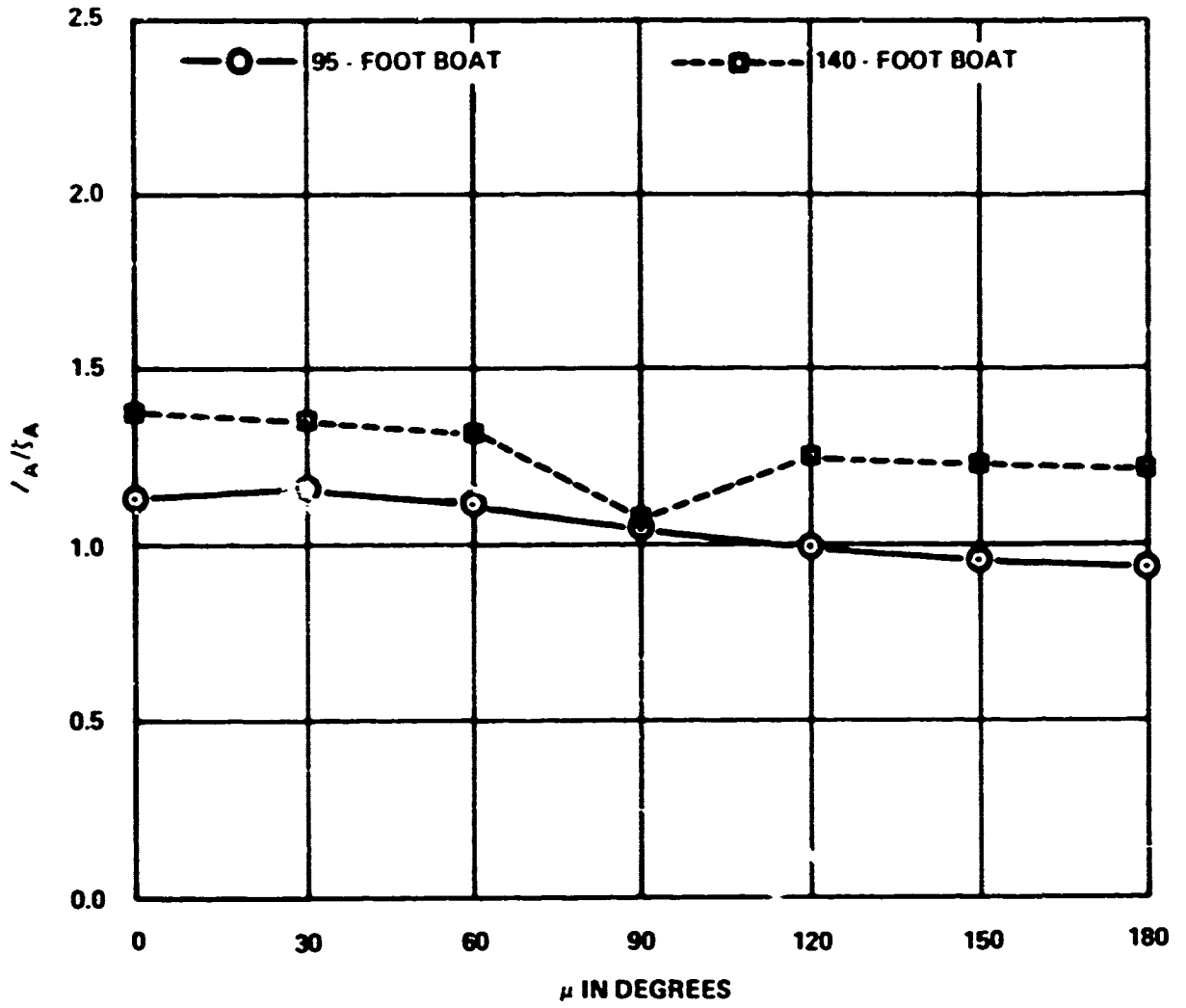

Figure 10 - Heave Maxima at $F_n = 0.27$

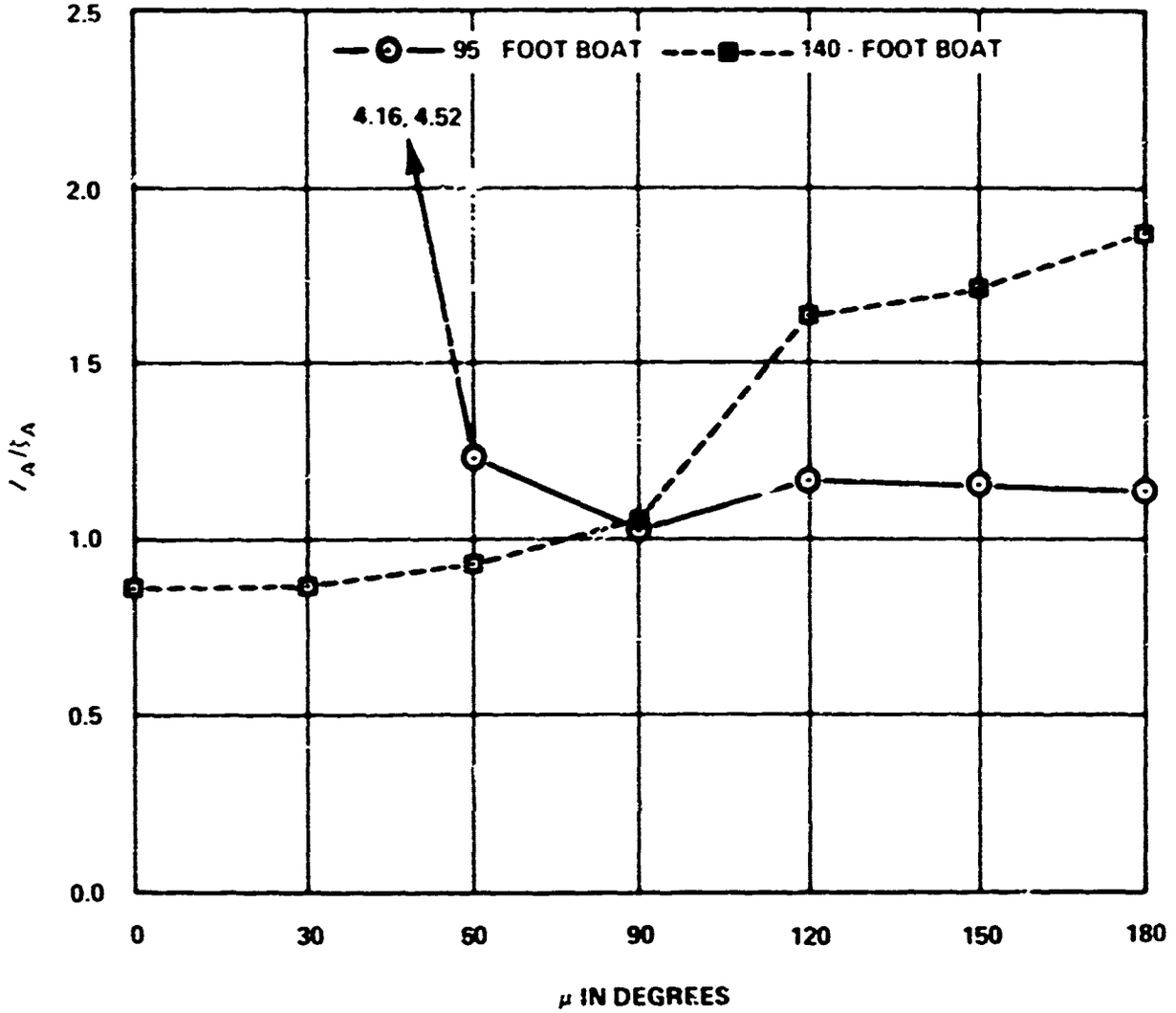

Figure 11 - Heave Maxima at $F_n = 0.44$

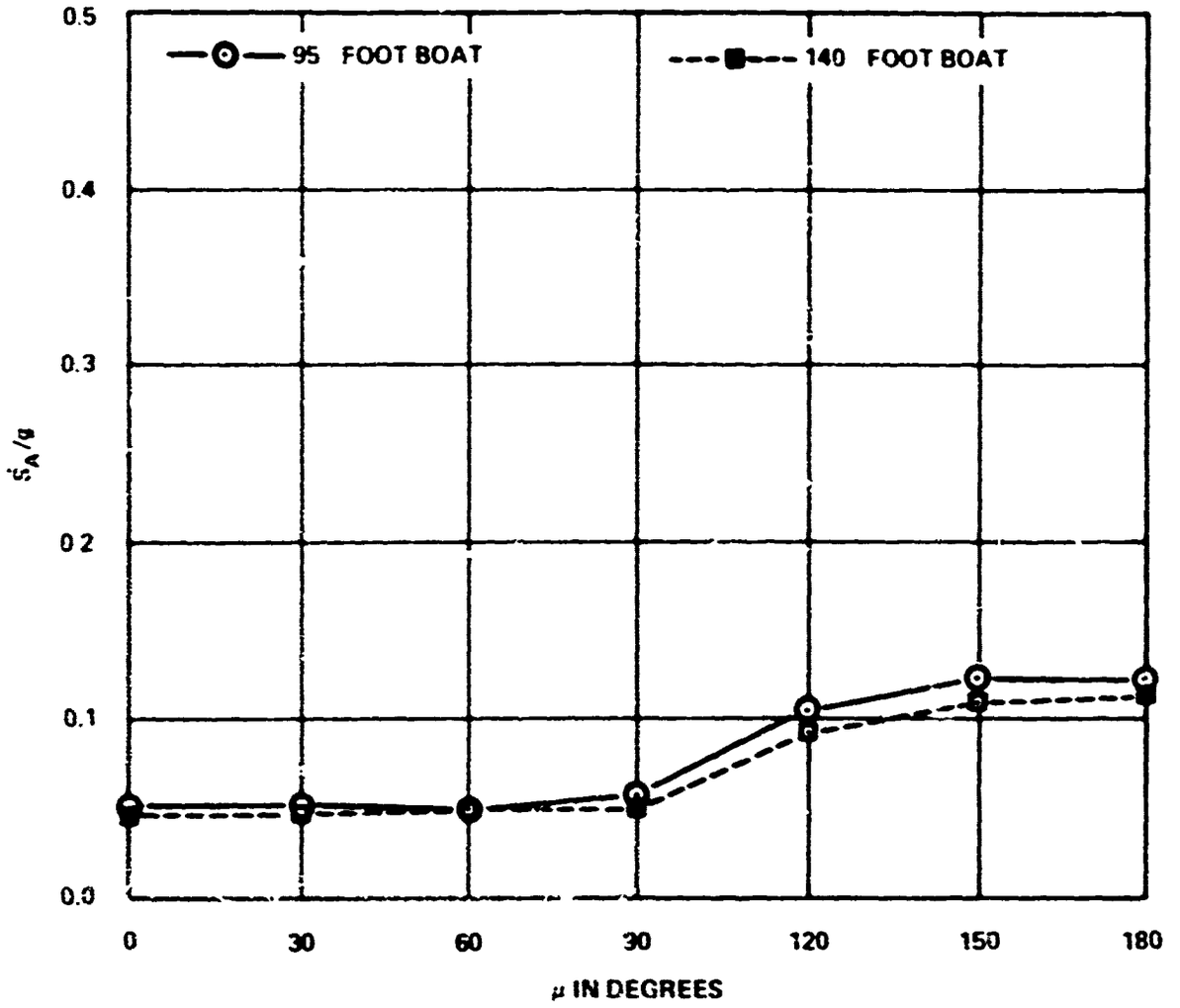

Figure 12 - Acceleration Maxima at $F_r = 0.10$

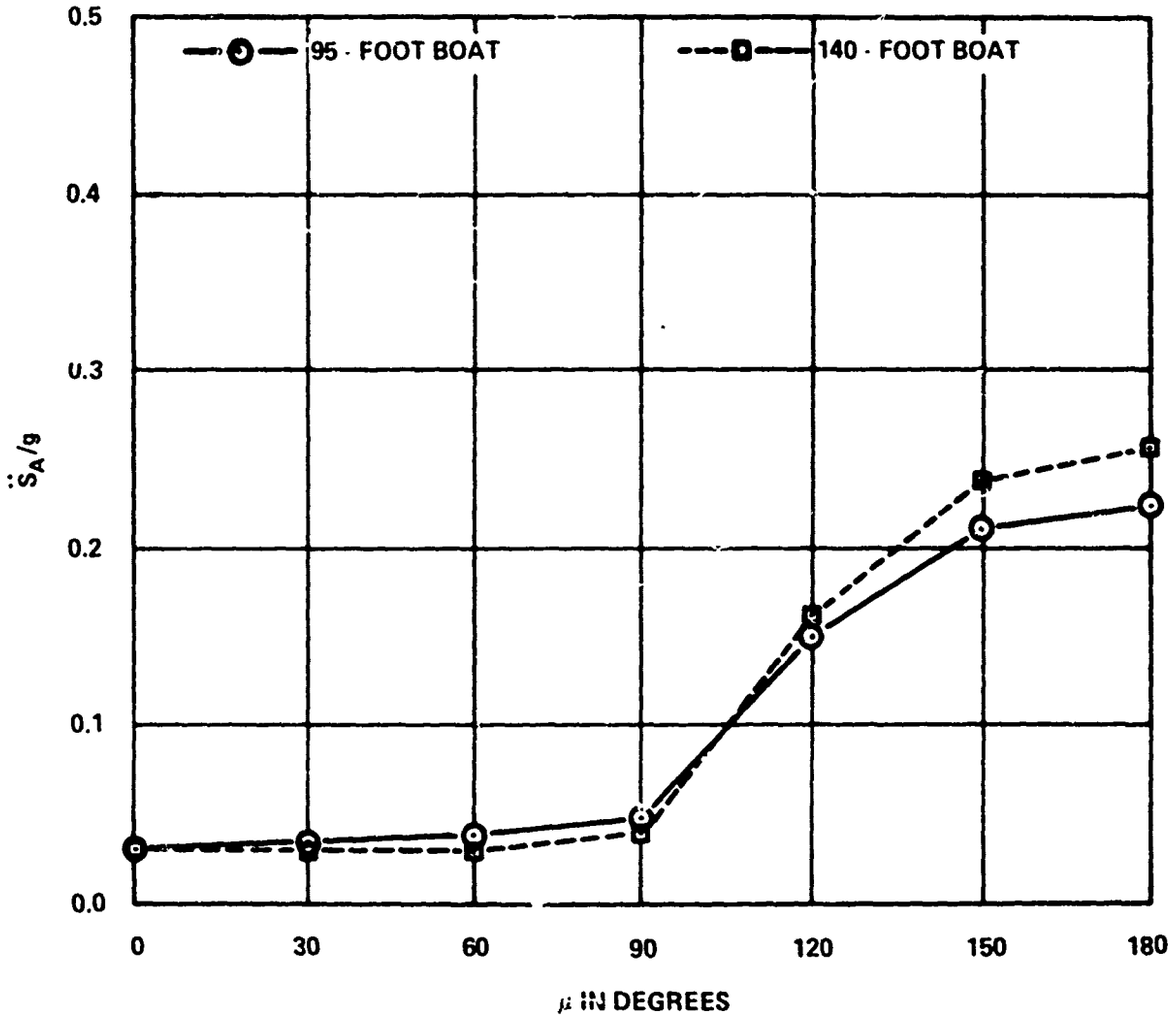

Figure 13 - Acceleration Maxima at $F_n = 0.27$

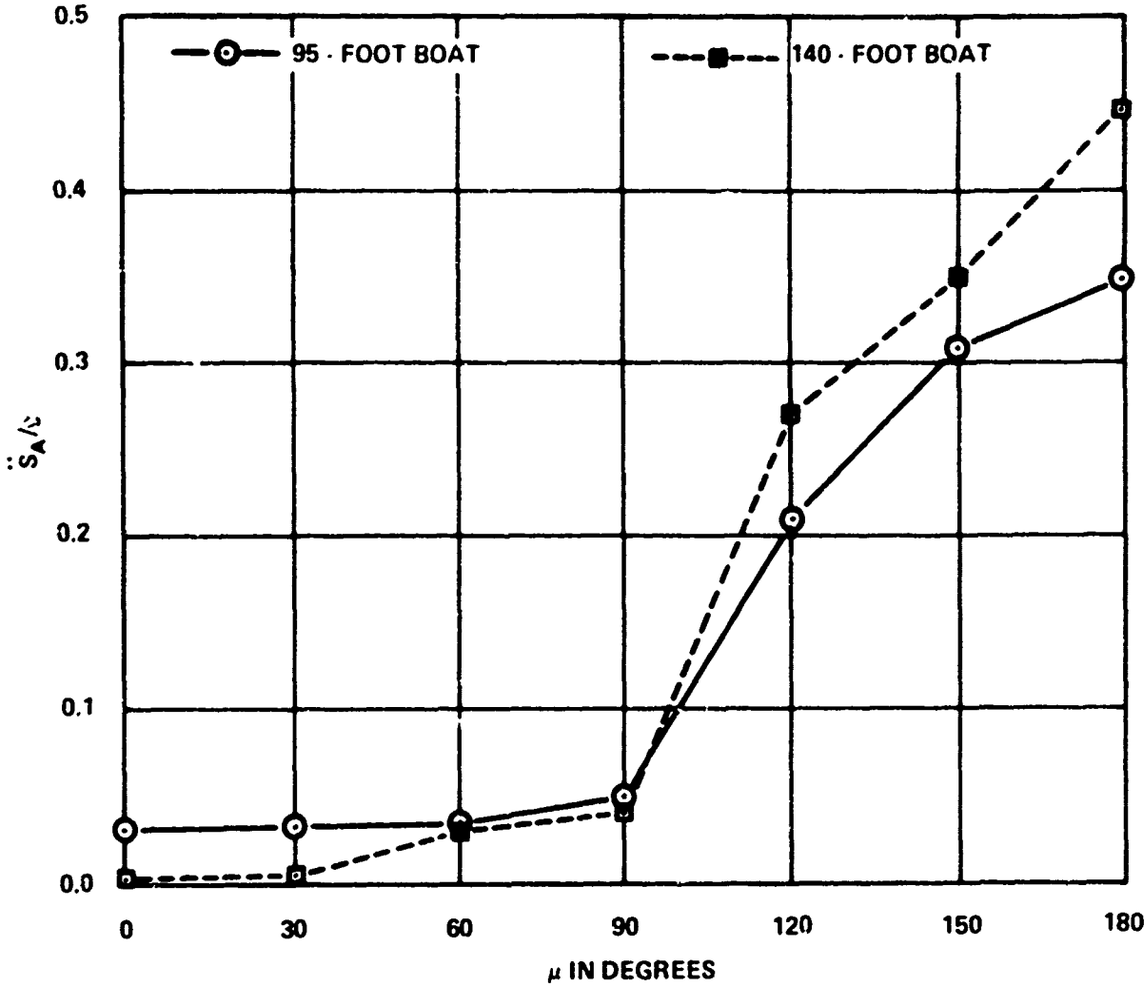

Figure 14 - Acceleration Maxima at $F_n = 0.44$

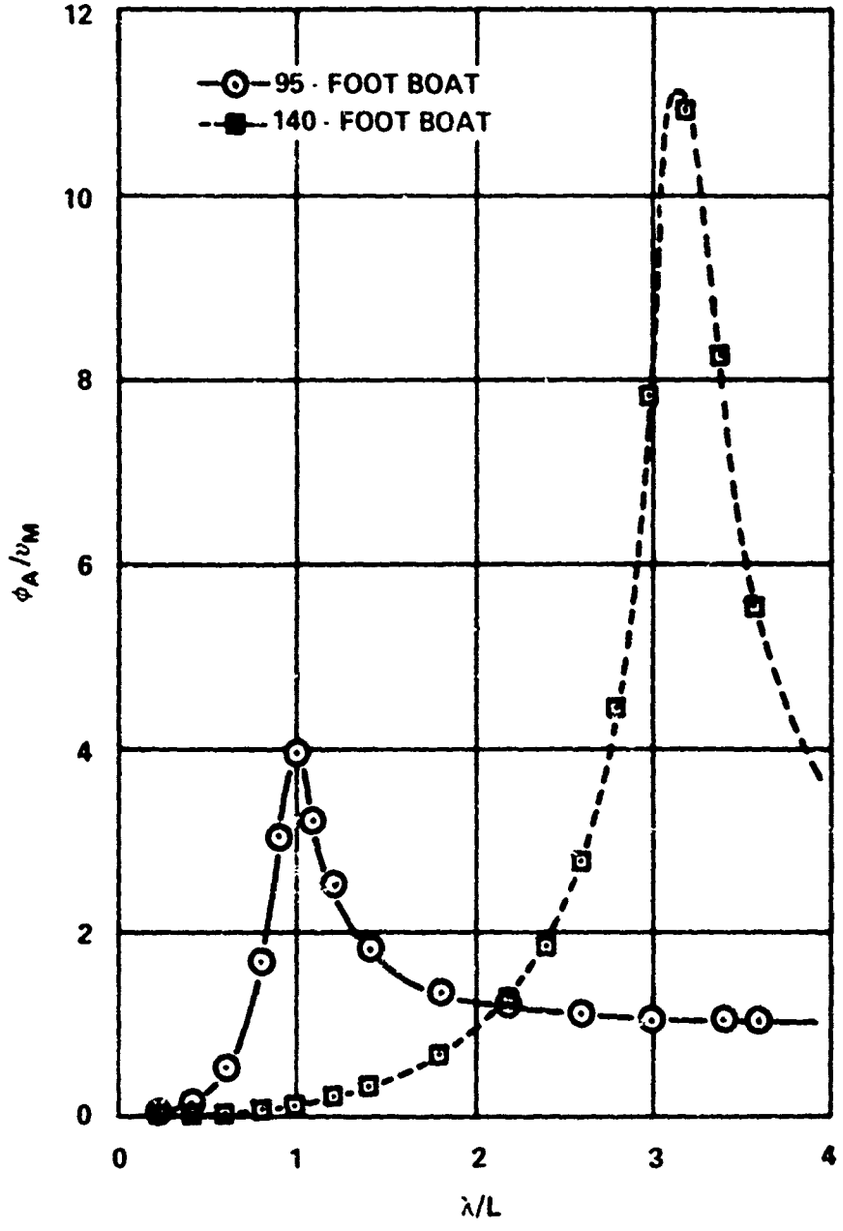

Figure 15 - Roll Transfer Functions at μ = 90 Degrees and F_n = 0.10

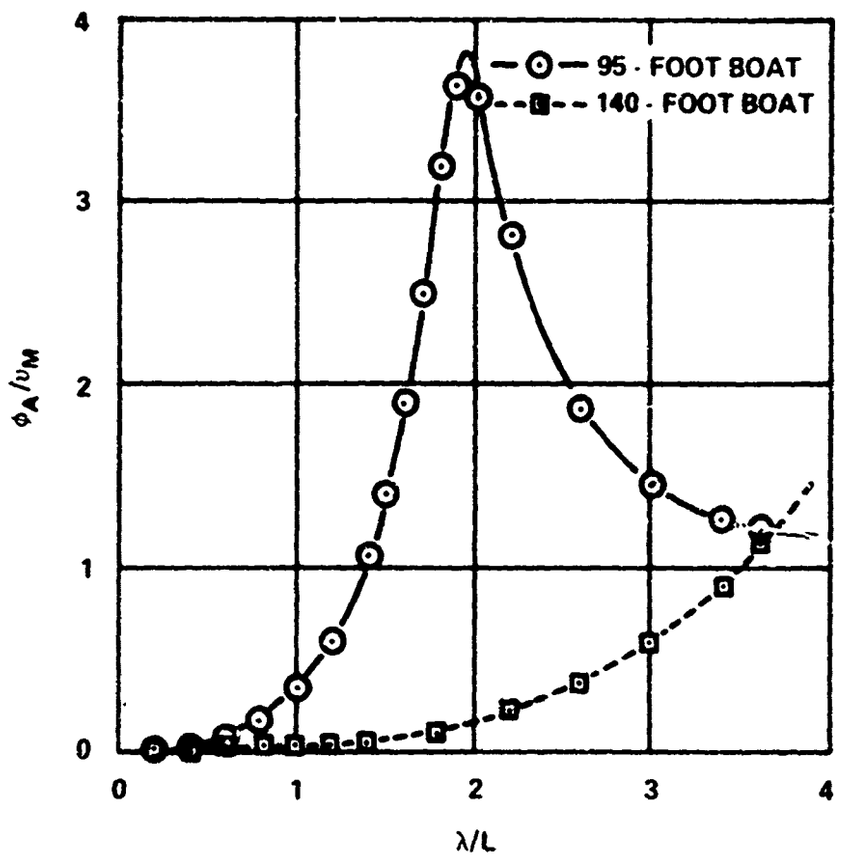

Figure 16 - Roll Transfer Functions at μ = 120 Degrees and F_n = 0.44

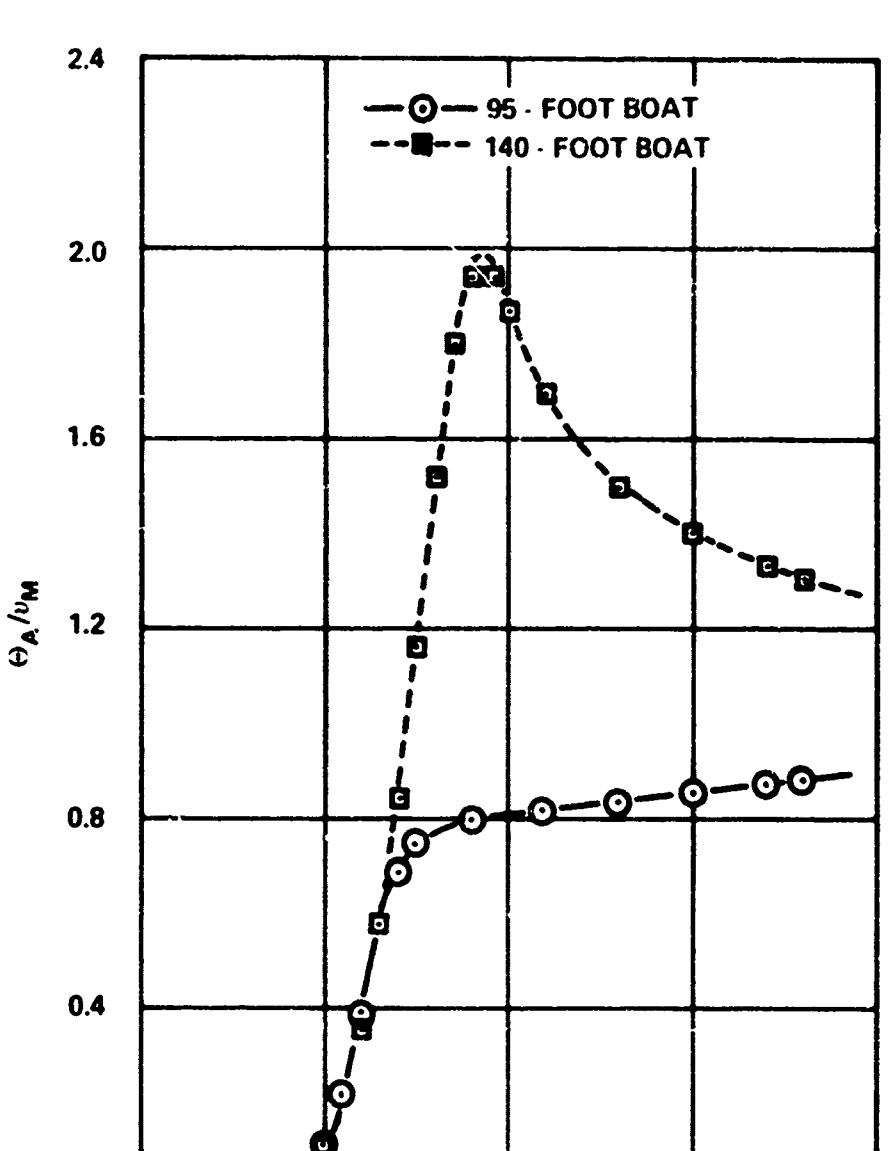

Figure 17 - Pitch Transfer Functions at μ = 180 Degrees and F_n = 0.44

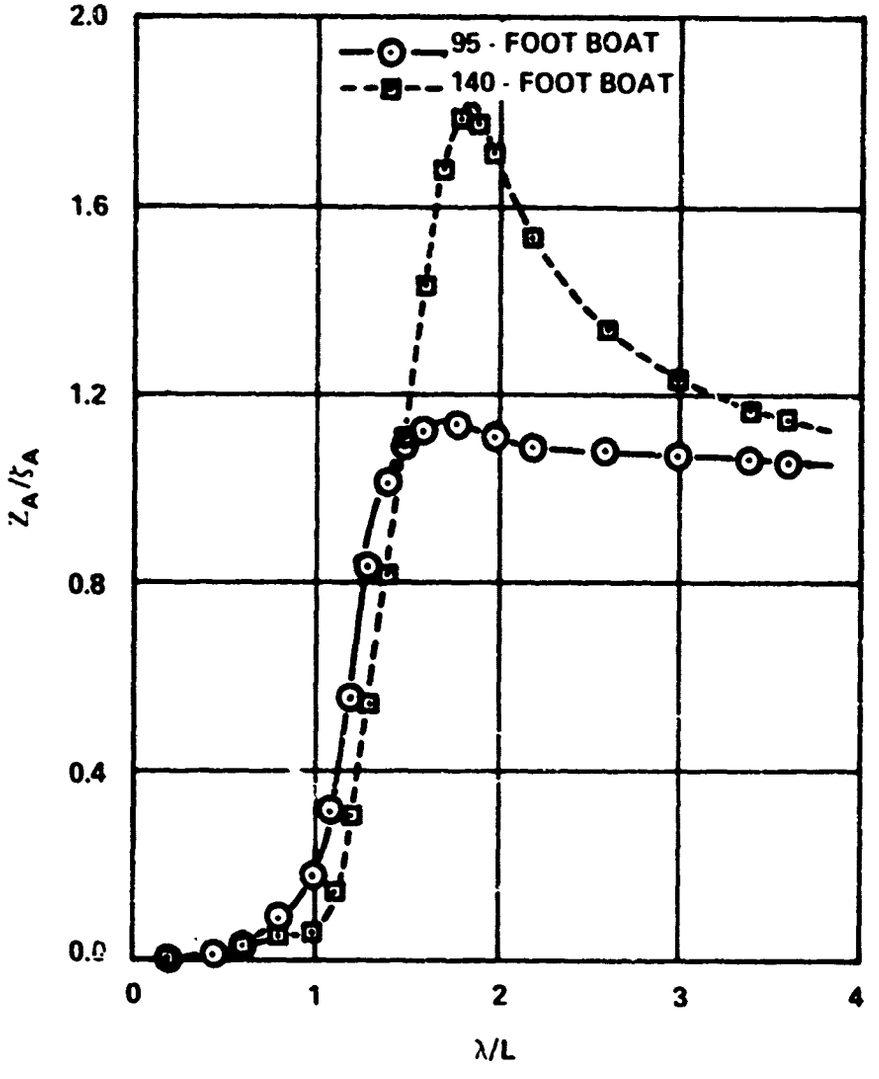

Figure 18 - Heave Transfer Functions at μ = 180 Degrees and F_n = 0.44

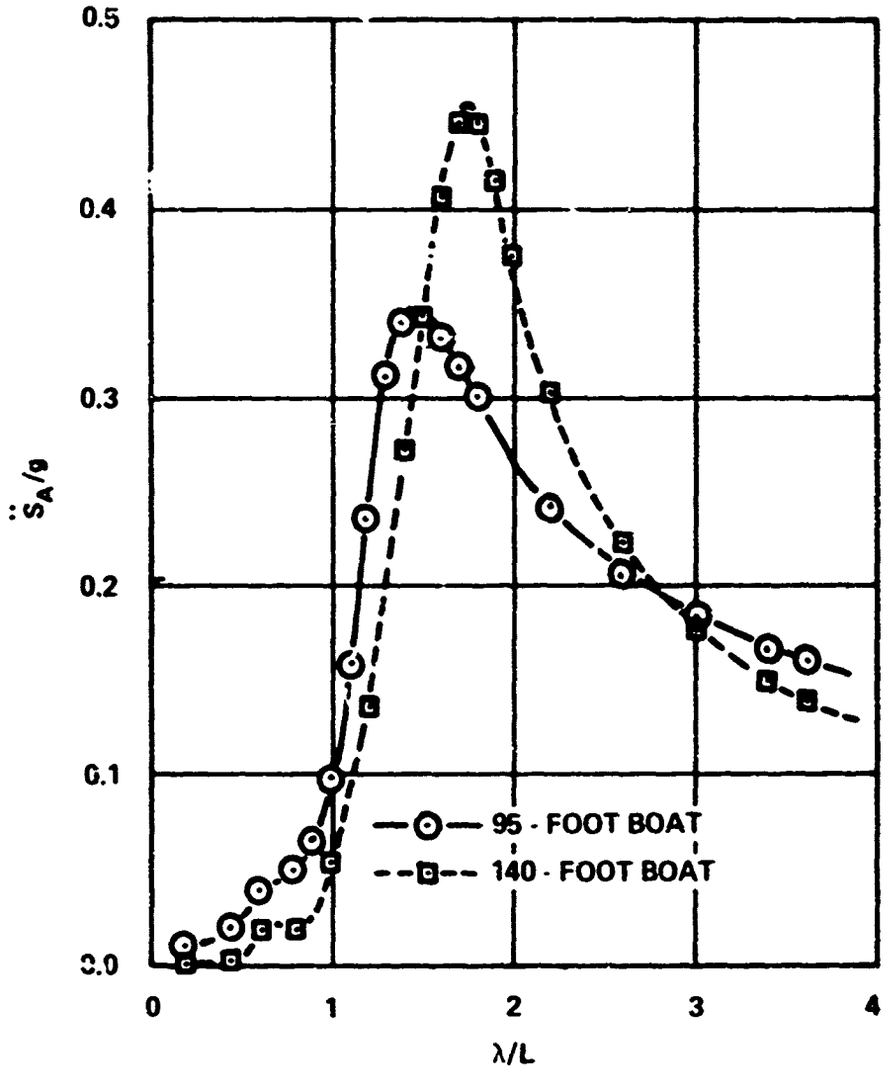

Figure 19 - Acceleration Transfer Functions at μ = 180 Degrees and F_n = 0.44

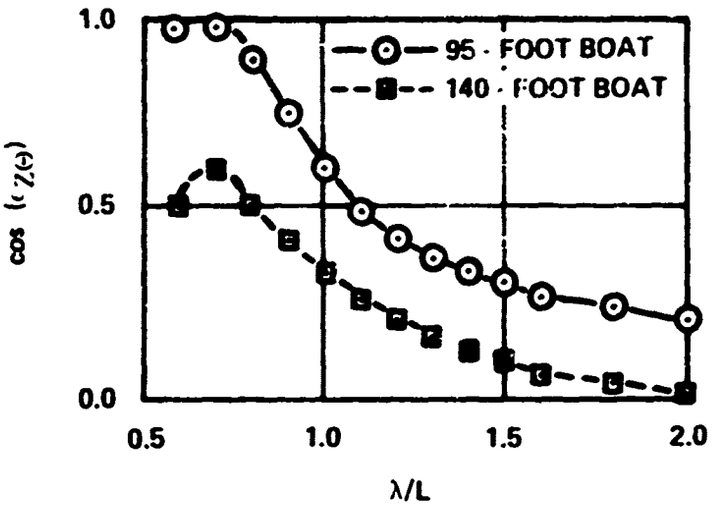

Figure 20 - Cosine of Heave-to-Pitch Phase Angles at μ = 150 Degrees and F_n = 0.10